

Mobility deserts, socioeconomic inequality, and emerging mobility services in U.S. metropolitan areas

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ABSTRACT

Urban mobility is central to the environmental, economic, and social sustainability of cities, yet access to transportation resources remains uneven across urban neighborhoods. This study develops a mobility index that captures neighborhood-level mobility constraints arising from the combined lack of public transportation and limited access to private vehicles. Integrating demographic data with geospatial information on bus and Metrorail infrastructure, we construct the index for census block groups across the nine largest U.S. metropolitan areas and identify “mobility deserts” as areas in the highest quartile of mobility deprivation within each region. The results reveal pronounced socioeconomic disparities between mobility deserts and non-mobility deserts, with mobility deprivation concentrated in socioeconomically vulnerable communities. By extending the transit desert framework, our approach provides a behaviorally grounded and scalable measure of mobility inequality that captures household mobility constraints. Our further assessment of emerging mobility services, such as bike-sharing systems, suggests that they may provide supplementary mobility options in selected mobility-deprived areas. However, their role is constrained by their tendency to co-locate with existing transit infrastructure rather than extend into the most underserved neighborhoods. Together, the findings underscore the importance of integrated, equity-oriented transportation policies that address structural mobility constraints while supporting environmentally sustainable urban transport systems, contributing to ongoing debates on accessibility, decarbonization, and inclusive transport planning.

1. Introduction

Urban mobility is a critical area of study because efficient transportation systems underpin the economic, environmental, and social sustainability of cities (Sultana et al., 2019). As more than half of the world's population now resides in urban areas, effective mobility is crucial for connecting residents to jobs, education, and essential services that sustain productivity and quality of life (Xu et al., 2025). At the same time, urban transport accounts for roughly one-quarter of global energy-related CO₂ emissions, and without sustained innovation in low-carbon mobility, these emissions are projected to double by 2050, intensifying climate change and air pollution (Creutzig et al., 2015). Moreover, a growing body of research demonstrates that accessible and affordable public transportation can mitigate spatial and socioeconomic inequalities by expanding access to employment, healthcare, and other opportunities, thereby fostering more inclusive urban environments

(Suel et al., 2024).

Over the past decade, the socioeconomic consequences of inadequate public transit systems have been increasingly documented. Limited transit access can constrain economic opportunities and depress labor-market outcomes (Lyons and Ewing, 2021), while shorter commutes and lower levels of spatial inequality are associated with improved intergenerational mobility and higher adult earnings for children raised in such contexts (Chetty et al., 2014). At the same time, wealthier residents tend to benefit from better-connected locations and greater modal choices, while lower-income neighborhoods face greater mobility constraints, particularly when car use is restricted (Lunke, 2022). These mobility disparities also intersect with broader racial and gender inequities in access to urban opportunities (Galaskiewicz et al., 2021; D'Agostino et al., 2024). Consequently, equitable investment in urban transportation infrastructure is essential for reducing these disparities and promoting inclusive urban development.

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The spatial allocation of transportation services is a central concern in the study of transportation injustice (Martens, 2016). Along this line, one widely used framework focuses on transit service gaps, often referred to as “transit deserts,” defined as areas where transit need is high, but transit supply is limited or absent (Jiao and Dillivan, 2013). Methodologically, a “transit gap” index is created by comparing measures of transit demand and transit supply across geographic units. Transit demand is typically estimated using demographic indicators that capture transit dependency, while transit supply is quantified via a combination of service characteristics. Areas that fall substantially below established accessibility thresholds are identified as transit deserts, signaling priority locations for policy intervention and infrastructure investment.

Building on the transit desert literature, this study develops a mobility index to characterize neighborhood-level access to both public and private transportation options, explicitly accounting for the population shares that rely on each mode. Research on transit desert is primarily centered on public transit, identifying areas where public transit supply is insufficient relative to the needs of populations who likely depend on it. In contrast, the mobility index broadens the analytical lens from public transit deficits alone to a more comprehensive understanding of neighborhood-level mobility deprivation. This measure, therefore, captures the combined availability of public transit and private vehicle access, reflecting a unified set of mobility constraints. In practical terms, areas with low mobility are neighborhoods where households have limited access to personal vehicles and are simultaneously underserved by public transportation, resulting in severely constrained travel opportunities.

We construct the mobility index at the census block group level by integrating demographic data with geospatial information on bus and Metrorail infrastructure across the nine largest metropolitan areas in the U.S. A mobility desert is further defined as a census block group that falls within the top quartile of the mobility index distribution within each metropolitan area, where a higher mobility index denotes a higher level of mobility deprivation. This approach allows for meaningful comparisons across regions with differing baseline levels of demographics and transportation supply. Using this classification, we also examine socioeconomic disparities between mobility deserts and non-mobility deserts. Finally, we assess whether emerging mobility services, such as bike-sharing systems, have the potential to alleviate mobility constraints in mobility deserts and partially offset gaps in traditional transportation provision.

This study makes three key contributions to the literature on transportation equity (Karner et al., 2020). First, we extend the transit desert framework by introducing the concept of mobility deserts, shifting the focus from public transit supply-demand mismatch to broader neighborhood-level mobility constraints. While transit deserts identify areas where public transit supply is insufficient relative to transit need (Jiao and Dillivan, 2013), mobility deserts capture a wider condition of constrained mobility arising from the combined lack of reliable public transportation and access to private mobility options. This distinction allows us to move beyond a transit-centered assessment of service gaps and examine whether residents have sufficient mobility resources across both public and private transportation systems. Second, by incorporating population reliance on different transportation modes into a unified index, our approach provides a behaviorally grounded measure of mobility inequality that can be readily constructed at various geographic scales. Third, we provide additional empirical evidence on the socioeconomic characteristics of mobility deserts across multiple major U.S. metropolitan areas and evaluate the role of emerging mobility services in mitigating these constraints. Together, our findings highlight the importance of moving beyond transit-centric frameworks toward a more holistic understanding of urban mobility inequality.

2. Literature review

2.1. Transport accessibility and measures of transit deserts

The concept of transit deserts was developed to identify areas where public transit provision is insufficient relative to the needs of transit-dependent populations. Jiao and Dillivan (2013) first introduced this concept and operationalized transit disadvantage as a spatial gap between transit demand and transit supply. In this early framework, transit demand referred to the need for public transportation among transit-dependent residents, while transit supply captured the level of public transit service available within a given area. A transit desert is therefore identified when transit demand exceeds transit supply. This demand-supply gap framework established an important methodological foundation for connecting public transportation provision with transportation equity, as areas with high transit dependency and inadequate service often reflect broader patterns of socioeconomic disadvantage.

Building on this framework, subsequent studies have refined the measurement of both transit demand and transit supply. On the demand side, researchers have incorporated broader indicators of transit dependency and social vulnerability, including income, employment status, age, disability, race, and car ownership (Aman and Smith-Colin, 2020; Yadav et al., 2026). On the supply side, measurement has moved beyond simple proximity-based indicators toward more comprehensive assessments of transit accessibility, such as connectivity to the network, connectivity to destinations, service frequency, flexibility, and time efficiency (Cai et al., 2020; Ermagun and Witlox, 2024). This development marks an important methodological shift: nearby transit infrastructure does not necessarily translate into effective accessibility if service is infrequent, destinations are difficult to reach, or travel times are excessive.

More recent research has further extended the analysis of transit deserts by incorporating commuting flows, temporal variation, and access to essential services. Studies using mobile phone or location-based data show that transit demand and transit gaps may vary across both space and time, particularly between peak and off-peak periods or between central and suburban areas (Cai et al., 2020; Lee et al., 2021). Other studies have shifted attention from access to the transit system itself to access by transit to socially necessary destinations, such as jobs, healthcare facilities, food stores, schools, and childcare services (Guo and Brakewood, 2024). These approaches broaden the meaning of transit accessibility by showing that inadequate transit provision can overlap with, and potentially reinforce, other forms of spatial and socioeconomic deprivation.

Another methodological development involves integrating established accessibility tools into transit desert and equity analysis. Public Transport Accessibility Levels, for instance, have been combined with transit gap measures to distinguish areas where poor accessibility results from insufficient supply from those where high demand overwhelms otherwise adequate supply (Yadav et al., 2024). Related studies further incorporate social vulnerability indicators to examine whether disadvantaged populations are disproportionately concentrated in areas with low accessibility and high transit gaps (Yadav et al., 2026). Together, these studies show that the measurement of transit deserts has evolved from relatively simple spatial gap analysis toward more multidimensional assessments of accessibility, demand, service quality, and equity.

Overall, existing studies provide a strong methodological basis for identifying transit deserts and evaluating transit-related inequality. However, most approaches remain centered on public transit systems. They primarily assess whether transit supply is sufficient for populations presumed to depend on public transportation, while paying less attention to broader neighborhood-level mobility constraints that arise from the combined lack of public transit access and limited private vehicle availability. This transit-centered focus leaves room for a broader mobility-based perspective. Accordingly, this study extends the transit desert framework by developing a mobility index that captures both

public transit access and private mobility constraints, thereby identifying mobility deserts as areas where residents face more comprehensive limitations in urban mobility.

2.2. Emerging mobility services in urban areas

Emerging mobility services, including shared e-bikes, e-scooters, and ride-hailing, offer flexible, on-demand options that can enhance household mobility in urban areas. Key mechanisms include mode substitution away from private cars (especially short trips), complementarity with public transit (e.g., first- and last-mile connections), reductions in household vehicle ownership, and expanded trip-making or accessibility, particularly for car-light or lower-income households.

With the advent of ride-hailing services like Uber and Lyft, travelers have a new potential to gain mobility without high car purchase costs and in the absence of reliable transit services. Barajas and Brown (2021) examined whether ride-hailing compensates for transit service gaps in Chicago by comparing transit supply with ride-hailing origins and destinations. They found lower ride-hailing activity in bus-dominated neighborhoods but significantly higher activity in rail-served areas, with distinct patterns for overnight weekend trips. Using data from the 2017 National Household Travel Survey across 42 U.S. metropolitan areas, Wang et al. (2021) explored the relationship between ride-hailing use and household vehicle ownership, finding that regular and active users were more likely to own fewer vehicles than occasional users, with no significant differences between regular and active users. Extending this line of inquiry, Qiao and Yeh (2023) combined survey and ride-hailing order data to assess the affordability-based substitutability of ride-hailing for public transit. They showed that 38% of ride-hailing trips could be made by transit overall, rising to 80% for commuting trips. For non-work travel, particularly entertainment, ride-hailing served as a flexible alternative for low-income households who previously lacked access to private vehicles, indicating that ride-hailing both competes with and complements public transit for different purposes and populations.

Dockless e-bike-share systems can reduce vehicle miles traveled (VMT) and associated emissions when they substitute for car trips. Using system-level trip data and individual-level survey responses from Sacramento, California, Fukushige et al. (2023) found that 28% of weekday e-bike-share trips replaced car travel (including private vehicles and ride-hailing), resulting in an estimated VMT reduction of 2131 miles per day, or 0.79 miles per trip. At the household level, Sun et al. (2024), drawing on 2020 travel survey data from Wuhan, China, identified household wealth as the primary determinant of car ownership, with e-bike ownership emerging as an important mitigating factor. Complementing these findings, Yin et al. (2024) used travel survey data from Jiading, Shanghai, to show that e-bike ownership can reduce car mode share by up to 19% in dual-mode households. E-bike ownership further encourages a broader range of non-commuting activities and enhances mobility for older adults, while only slightly reducing public transport use. Together, these studies suggest that e-bikes both substitute for car travel and complement transit services.

Shared e-scooters have the potential to complement public transit by addressing first- and last-mile gaps. Using survey data from Washington, D.C., and Los Angeles, Yan et al. (2023) found that many users rely on shared e-scooters to connect with transit and substitute for car trips. Integration between e-scooters and transit was stronger among non-White respondents, with no significant differences by gender, age, income, or education. At a broader scale, Li et al. (2024) examined e-scooter-transit integration in 124 European cities, finding substantial variation in integration ratios (ranging from 5.59% to 51.40%) and opposite temporal trends for first- and last-mile trips, whereby increases in first-mile integration coincided with declines in last-mile integration. Focusing on Gothenburg, Sweden, Hu et al. (2025) showed that e-scooters can significantly enhance accessibility within a 30-min travel time, with 15% of areas experiencing statistically significant gains.

While high-income and native-born communities saw the largest average improvements, some low-income and foreign-born neighborhoods, those currently reliant on transit but underserved by e-scooters, could achieve accessibility gains of up to 143% if shared e-scooter services were introduced.

3. Data and methods

3.1. Study areas

Our study covers the nine largest U.S. metropolitan areas with operating Metrorail or subway systems, including Baltimore (Maryland), Boston (Massachusetts), Chicago (Illinois), Los Angeles (California), Miami (Florida), New York City (New York), Philadelphia (Pennsylvania), San Francisco (California), and Washington, DC (Fig. 1). These regions were selected because they represent major urban settings in the U.S., where rail transit systems, bus networks, private vehicle use, and emerging mobility services coexist. Smaller cities, rural areas, and regions without Metrorail or subway systems are therefore beyond the scope of this study, as they may exhibit different forms of mobility constraint. This comparative framework allows us to examine mobility deprivation across metropolitan areas that share core transit infrastructure, while differing substantially in transit provision, vehicle access, and commuting patterns.

Populations in these study areas range from approximately 570,000 in Baltimore to over 8 million in New York City, with an average population of 3.9 million. For areas with officially defined metropolitan boundaries, such as Baltimore and Chicago, we adopt those boundaries directly. For areas without clearly delineated city limits, including Los Angeles and San Francisco, boundaries are manually constructed based on empirical metropolitan area coverage. To capture fine-scale spatial variation within each study area, our analysis is conducted at the census block group level. Census block groups are statistical subdivisions of census tracts and typically contain between 600 and 3000 residents and 250 to 550 housing units, according to U.S. Census definitions. This spatial resolution allows us to examine intra-urban heterogeneity with sufficient geographic detail.

3.2. Metrorail stations, bus stops, and bike-sharing stations

We compiled public transportation data, including Metrorail or subway stations, bus stops, and bike-sharing stations, from each area's open GIS data portal and supplementary sources (see Supplementary Table S1 for data descriptions and links). Public transportation coverage varies substantially across the nine metropolitan areas (Table 1). For example, New York City's subway system comprises 25 routes operating across 496 stations and more than 665 miles of track, whereas Baltimore operates a single metro line (the Metro SubwayLink) with only 14 stations and 15.5 miles of service. Bus networks and bike-sharing systems also differ markedly across areas. Philadelphia has the largest number of bus stops (over 22,000) among the study areas but one of the smallest bike-sharing systems (fewer than 300 stations). In contrast, Miami has a much smaller bus network (approximately 6000 bus stops) but a relatively extensive bike-sharing system, with more than 1600 stations.

To measure public transit accessibility, we constructed several indicators capturing access to different transportation modes at the census block group level, including distance to the nearest Metrorail station, bus stop density, distance to the nearest bike-sharing station, and bike-sharing station density. Because Metrorail systems operate as fixed-route, rail-based rapid transit, we calculated the distance from each census block group to its nearest Metrorail station. Shorter distances thus indicate higher levels of Metrorail accessibility. Given that multiple bus stops typically fall within a census block group, we measured bus accessibility using bus stop density rather than distance to the nearest bus stop. Recognizing that individuals are generally willing to walk short distances (approximately 400 m, or 0.25 miles) to access bus

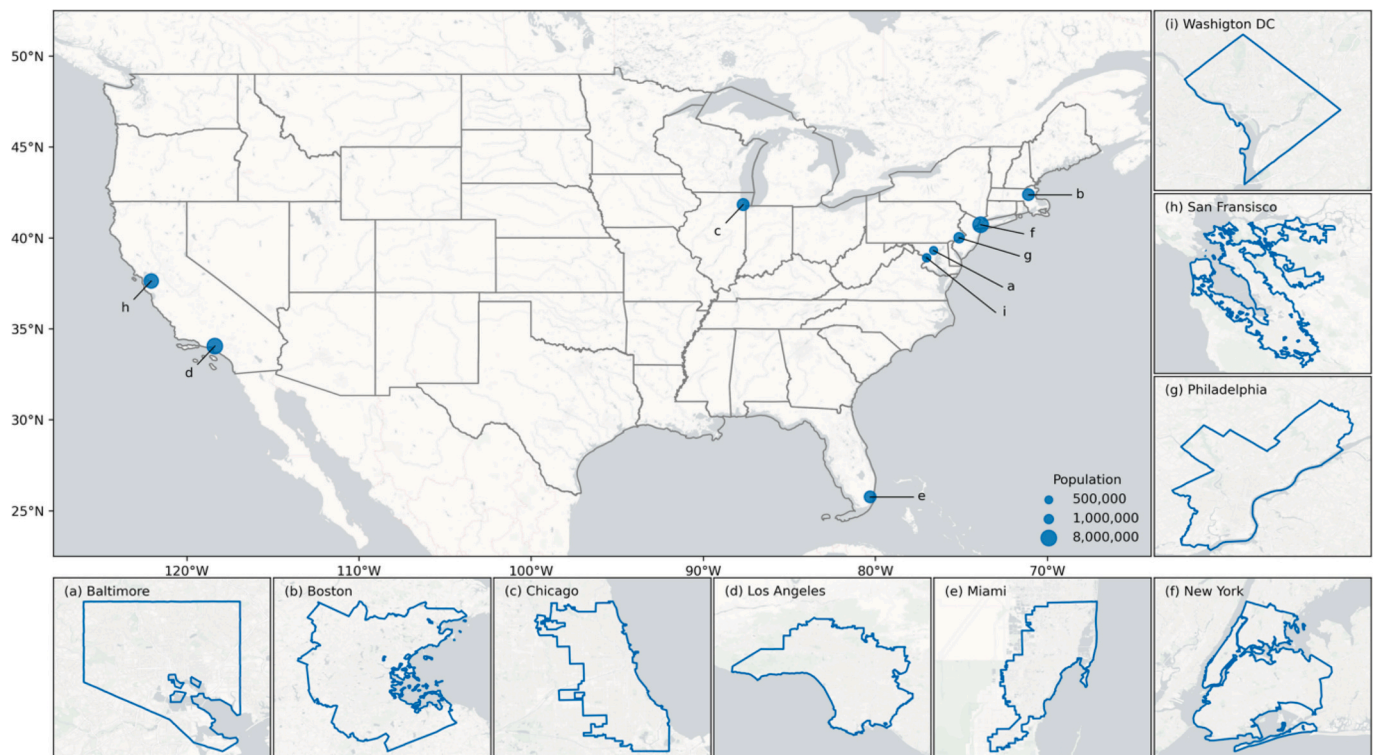


Fig. 1. Study areas.

Table 1
Statistics for the nine metropolitan areas.

Metropolitan area	Number of block groups	Total population	Number of Metrorail stations	Number of bus stops	Number of bike-sharing stations
Baltimore	611	570,791	14	2654	39
Boston	1660	2,582,941	170	7810	421
Chicago	2153	2,704,814	145	10,760	1149
Los Angeles	5466	7,968,547	107	11,840	437
Miami	1798	2,612,354	23	6501	1658
New York City	6040	8,005,943	496	17,126	1907
Philadelphia	1265	1,575,943	156	22,478	293
San Francisco	3820	5,681,967	423	5810	531
Washington, DC	550	664,333	98	8289	819

services (El-Geneidy et al., 2010), we calculated bus stop density based on the total number of bus stops within a 400-m buffer around each block group. For bike-sharing systems, we used two complementary measures: distance to the nearest bike-sharing station and bike-sharing station density. These two indicators capture both proximity and overall availability, allowing us to assess the role of bike sharing as an alternative or complementary mobility option to Metrorail and bus services.

Several data boundaries should be noted. These stop- and station-based measures capture the spatial availability and proximity of transportation resources, but they do not directly account for service quality, such as frequency, reliability, operating hours, or actual travel times. In addition, the analysis of emerging mobility services focuses on station-based bike-sharing systems, as comparable cross-city data for ride-hailing and e-scooters were not consistently available.

3.3. Census block group variables

To capture public transportation demand at the census block group level, we used data from the 2019–2023 American Community Survey (ACS) 5-year estimates, focusing on the percentage of occupied housing units without access to a vehicle. Higher values of this indicator reflect

lower private mobility and greater reliance on public transportation options. We also incorporated commuting mode shares, specifically, the percentage of workers commuting by car, metro, and bus, to account for observed transportation choices and adjust for baseline commuting behavior.

To further examine the socioeconomic characteristics associated with transportation demand and mobility constraints, we included a set of variables from the ACS. These include total population; age composition (ages 0–18, 18–34, 35–64, and 65 and older); gender; race and ethnicity (percent White, Black, Asian, and Hispanic); educational attainment (percentage of adults aged 25 and older with a bachelor's degree or higher); median household income; and the unemployment rate (percentage of unemployed individuals among the labor force aged 16 and older).

3.4. Mobility index construction

We constructed a mobility index to characterize census block group-level access to both public and private transportation options, explicitly accounting for population reliance on each mode. The index is intended to capture structural constraints in neighborhood-level mobility options rather than to represent all possible dimensions of transportation service

quality or daily travel behavior. To maintain a parsimonious and comparable measure across metropolitan areas, we focus on three indicators that reflect the dominant private and fixed-route public transportation resources in the study regions: the percentage of occupied housing units without a vehicle, the distance to the nearest Metrorail station, and bus stop density. The first indicator captures limited access to private mobility, while the latter two capture access to high-capacity rail transit and the local availability of fixed-route bus services, respectively.

The selection of these indicators is further supported by observed commuting patterns across the nine metropolitan areas in this study. On average, trips by car, Metrorail, and bus accounts for approximately 72% of all commutes, with shares of about 54%, 11%, and 7%, respectively. Because these three modes cover the majority of observed commuting activities, the selected indicators provide a broadly representative basis for capturing the core mobility resources that shape neighborhood-level mobility deprivation. Since these variables are measured on different scales, we first standardized each indicator using city-specific Z-scores as follows:

$$Z_{ij}^k = (X_{ij}^k - \mu_j^k) / \delta_j^k \quad (1)$$

where Z_{ij}^k denotes the Z-score for variable k ($k = car, metro, bus$) for block group i in city j ; X_{ij}^k is the raw value; and μ_j^k and δ_j^k are the city-level mean and standard deviation, respectively. This standardization is conducted separately within each metropolitan area rather than across the pooled sample. Thus, the mobility index identifies neighborhoods that are relatively mobility-deprived within their own metropolitan area, rather than comparing absolute mobility conditions across cities.

After standardization, we aligned the direction of all indicators so that higher values consistently indicate greater mobility deprivation. The percentage of occupied housing units without a vehicle and the distance to the nearest Metrorail station already conform to this orientation, as higher values reflect more limited private vehicle access and poorer rail accessibility. In contrast, bus stop density is an accessibility-oriented measure, with higher values indicating greater bus availability and therefore lower mobility deprivation. We therefore reverse-coded the standardized bus stop density before incorporating it into the index:

$$Z_{ij}^{(Bus, rev)} = -Z_{ij}^{Bus} = (\mu_j^{Bus} - X_{ij}^{Bus}) / \delta_j^{Bus} \quad (2)$$

We then used commuting mode shares as behavioral weights to account for local reliance on different transportation modes. This weighting strategy is consistent with recent transit accessibility and transit gap research that weights transportation components according to observed work-trip mode shares rather than treating all components as equally important (Yadav et al., 2024). The rationale is that the same mobility constraint may have different implications depending on how residents typically travel. For example, limited bus availability is more consequential in neighborhoods with higher bus commuting shares, while limited rail access matters more where rail commuting is more common. Similarly, limited private vehicle access may represent a stronger mobility constraint in neighborhoods where commuting remains highly automobile-oriented. This weighting strategy therefore allows the index to reflect locally observed mode reliance across neighborhoods. The mobility index was therefore calculated as follows:

$$Z_{ij}^{MI} = \alpha_{ij} Z_{ij}^{Car} + \beta_{ij} Z_{ij}^{Metro} + \gamma_{ij} Z_{ij}^{(Bus, rev)} \quad (3)$$

where α_{ij} , β_{ij} , and γ_{ij} are the weights derived from commuting mode shares, i.e., the percentages of workers commuting by car, metro, and bus, based on the ACS 2019–2023 data.

A mobility desert is further defined as a census block group that falls within the top quartile of the mobility index distribution within each metropolitan area. We adopted this quartile-based threshold in line with prior research on transit equity and transit deserts, where quartiles are commonly used to identify areas with relatively high transit dependency

or low transit provision (Aman and Smith-Colin, 2020). This relative classification is particularly suitable for our multi-city analysis, as the study areas differ in transit infrastructure, vehicle access, and commuting patterns. It therefore identifies the most mobility-deprived neighborhoods within each metropolitan area rather than imposing a uniform national cut-off. As a sensitivity analysis, we also used 20% and 30% as alternative cut-offs in our analysis.

3.5. Empirical model

Our empirical analysis proceeds in two complementary steps. We first use descriptive group comparisons to examine socioeconomic differences between mobility deserts and non-mobility deserts, as well as gradients across mobility index quartiles. We then estimate regression models to assess whether these patterns remain in a multivariate associational framework after accounting for metropolitan-area fixed effects. For the regression component, we first use a linear regression model with an ordinary least squares estimation to examine the relationship between socioeconomic characteristics and the mobility index. The model is specified as follows:

$$Z_{ij}^{MI} = \mathbf{X}_{ij} \boldsymbol{\beta} + \mu_j + \varepsilon_{ij} \quad (4)$$

where $\mathbf{X}_{ij}$ is a vector of socioeconomic characteristics for block group i in city j ; $\boldsymbol{\beta}$ denotes the corresponding coefficient estimates; μ_j is the city fixed effects to account for potential unobserved heterogeneity across cities; and ε_{ij} is an error term. The socioeconomic characteristics at the block group level include: total population (*Total population*), the percentage of male residents (*% Male*), the percentage of Black residents (*% Black*), the percentage of the population aged under 18 (*% Children*), the percentage of the population aged 65 and older (*% Senior*), the percentage of residents with a bachelor's degree (*% Bachelor*), median household income (*Median Income*), and the unemployment rate (*% Unemployment*). Robust standard errors are used to account for heteroskedasticity in the errors.

To examine the relationship between socioeconomic characteristics and whether a census block group is categorized as a mobility desert, we use a logit model as follows:

$$MD_{ij} = \mathbf{X}_{ij} \boldsymbol{\beta} + \mu_j + \varepsilon_{ij} \quad (5)$$

where $MD_{ij} = 1$ if block group i in city j is categorized as a mobility desert and everything else remains the same as specified in eq. (4).

4. Results

4.1. Summary statistics

Fig. 2 summarizes median access to private and public transportation across nine metropolitan areas. Fig. 2a reports the median share of households without vehicles, an indicator of private mobility access. The pooled median is 14.3%, with substantial cross-metropolitan variation. New York City exhibits the highest median carless rate (56.3%), followed by Washington, DC (32.2%), Philadelphia (24.5%), and Baltimore (23.7%), all well above the sample median. In contrast, Los Angeles (5.81%), Miami (5.38%), and San Francisco (5.15%) fall far below the sample median, indicating a stronger reliance on private automobiles.

Fig. 2b presents the median distance to the nearest Metrorail station. The overall median distance is 1.86 km. Metrorail access is greatest in New York City (0.58 km) and Washington, DC (1.06 km), while Boston (2.65 km), Baltimore (3.20 km), and Los Angeles (3.93 km) exhibit progressively weaker access. Miami is a clear outlier, with a median distance of 7.60 km, reflecting markedly limited Metrorail accessibility.

Fig. 2c shows median bus stop density as a measure of surface transit provision. The pooled median is 51.7 stops, though variation is pronounced. New York City (206) and Philadelphia (195) display

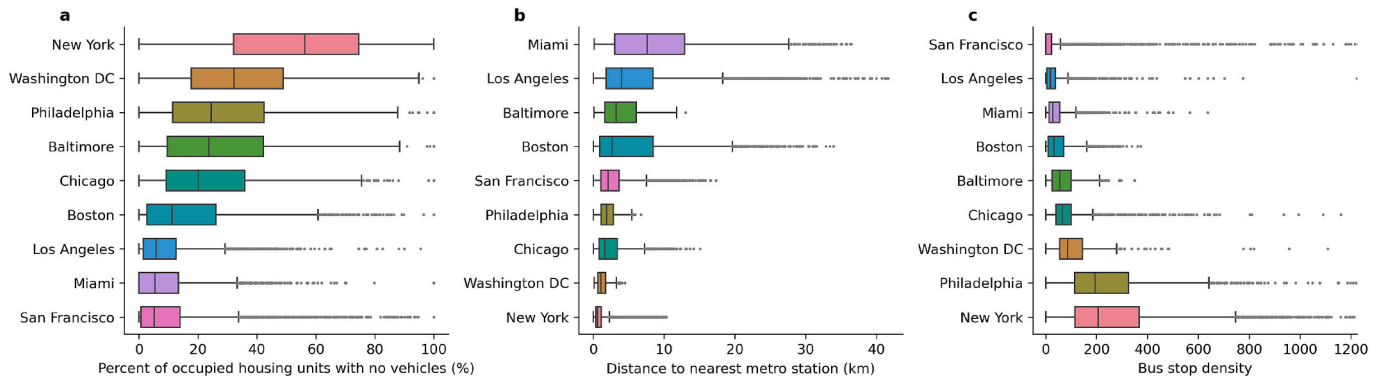


Fig. 2. Access to private vehicle and public transportation across metropolitan areas.

exceptionally high densities, whereas Boston (32.5), Miami (28.3), and Los Angeles (18.7) exhibit comparatively sparse coverage. San Francisco's median density of zero suggests the absence of bus stops in some spatial units and a highly uneven distribution of service.

Fig. 3 summarizes median commuting mode shares across nine metropolitan areas. Fig. 3a shows the median share of commuters traveling by private car. The pooled median car mode share is 57.9%, underscoring the continued dominance of automobiles in metropolitan commuting. Miami records the highest median share (80.0%), followed by Los Angeles (74.9%), Baltimore (63.0%), San Francisco (62.6%), Chicago (58.6%), all of which cluster above the overall median. In contrast, Washington, DC (31.4%) and, especially New York City (21.5%), exhibit substantially lower car reliance.

Fig. 3b reports median metro commuting shares. The pooled median is just 0.9%, indicating limited metro use across the sample. New York City stands out with a median share of 33.0%, followed by Washington, DC (9.72%), Boston (3.67%), and Chicago (3.40%). By comparison, Baltimore, Los Angeles, Miami, Philadelphia, and San Francisco show median metro shares of zero, suggesting that metro commuting in these regions is either minimal or highly concentrated in specific subareas.

Fig. 3c presents median bus commuting shares. The pooled median is 2.4%, indicating modest reliance on surface transit. Philadelphia (7.16%), New York City (6.74%), and Chicago (5.53%) report the highest median bus shares, while Washington, DC (3.97%) and Baltimore (4.59%) exhibit intermediate levels. In contrast, Boston (0.94%), Los Angeles (0.71%), San Francisco (0.60%), and Miami (0%) show very low bus usage, pointing to limited bus transit uptake in these metropolitan areas.

4.2. Mobility deserts are more socioeconomically vulnerable

This section presents the socioeconomic patterns associated with mobility deserts in two complementary components. Descriptive

comparisons first illustrate socioeconomic differences between mobility deserts and non-mobility deserts, as well as gradients across mobility index quartiles. Regression models then assess whether these patterns remain consistent in a multivariate associational framework.

Fig. 4 compares mean socioeconomic characteristics between census block groups classified as mobility deserts and non-mobility deserts. Mobility deserts are defined as block groups in the highest quartile of the mobility index, with all remaining block groups serving as the comparison group. Supplementary Figs. S1 and S2 using the top 20% and 30% thresholds, respectively, show consistent findings. As shown in Fig. 4, total population size does not differ significantly between the two groups (1354 vs. 1369; $P = 0.134$). In contrast, pronounced and statistically significant disparities emerge across most socioeconomic dimensions. Mobility desert block groups have a slightly lower share of male residents (47.9% vs. 49.0%; $P < 0.001$) and a substantially higher proportion of Black residents (25.4% vs. 15.1%; $P < 0.001$). Age composition also differs markedly: mobility deserts exhibit a lower share of children (18.6% vs. 19.3%; $P < 0.001$) and a higher share of seniors (17.0% vs. 15.9%; $P < 0.001$). Educational and economic disparities are particularly pronounced. Mobility desert block groups have a significantly lower share of residents with a bachelor's degree (34.8% vs. 45.4%; $P < 0.001$), substantially lower median household income (a gap of \$37,800; $P < 0.001$), and higher unemployment rates (5.1% vs. 4.2%; $P < 0.001$).

Fig. 5 further disaggregates census block groups by quartiles of the mobility index (Q1–Q4), where Q1 represents the least mobility-deprived areas and Q4 the most severe mobility desert conditions. This stratification reveals systematic socioeconomic gradients that are consistent with the earlier binary comparison. Several indicators exhibit clear monotonic patterns. The share of male residents declines steadily from 49.3% in Q1 to 47.9% in Q4 (Fig. 5b), while the proportion of Black residents rises sharply from 14.2% to 25.4% (Fig. 5c). Unemployment rates also increase monotonically, from 4.0% in Q1 to 5.1% in Q4

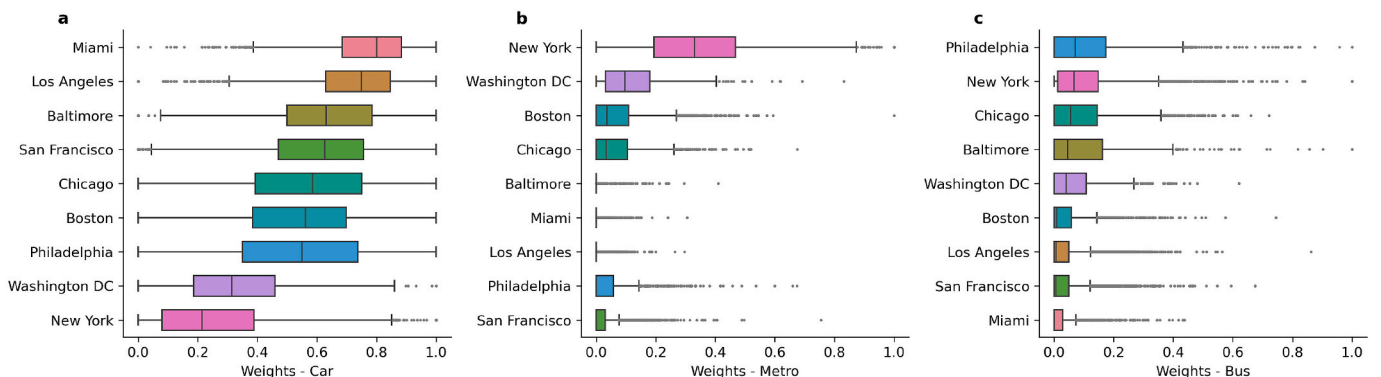


Fig. 3. Share of population using private vehicle and public transportation across metropolitan areas.

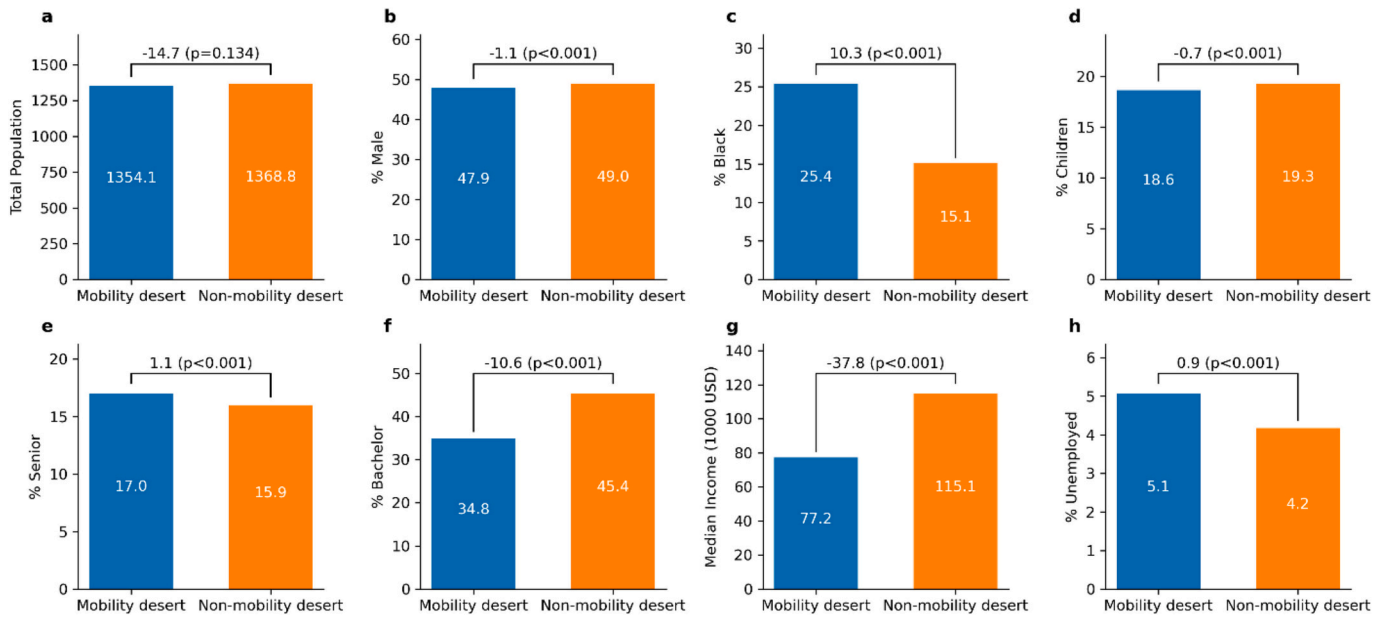


Fig. 4. Socioeconomic disparities between mobility deserts and non-mobility deserts.

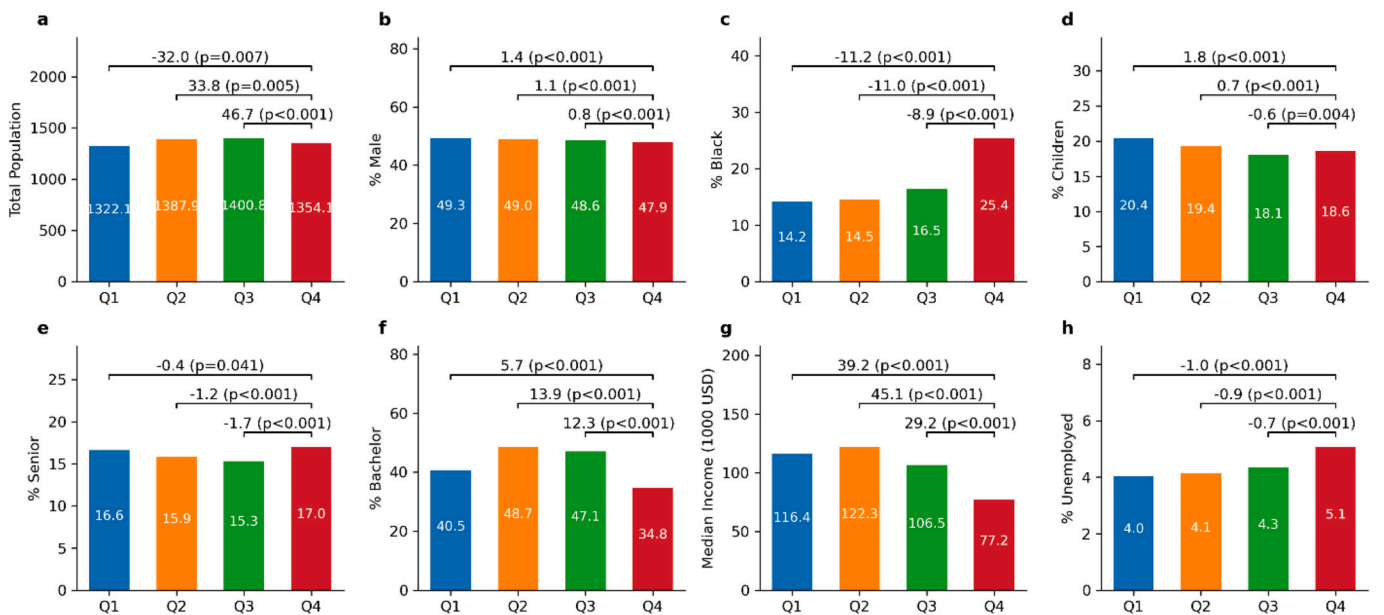


Fig. 5. Socioeconomic disparities across block groups by mobility index quartile.

(Fig. 5h).

Other socioeconomic characteristics display less strictly monotonic but still pronounced differences. Median household income declines substantially in the most mobility-deprived areas, falling to \$77,200 in Q4 compared with over \$100,000 in the lower quartiles (Fig. 5g). Educational attainment follows a similar pattern: while Q2 and Q3 show relatively higher shares of residents with a bachelor's degree, Q4 records a markedly lower level (Fig. 5f). Differences in age structure and population size are more modest, with Q4 block groups exhibiting slightly smaller populations, fewer children, and a higher share of older adults (Figs. 5a, d-e).

Fig. 6 presents regression estimates of the socioeconomic factors associated with mobility using two complementary specifications. Supplementary Figs. S3 and S4 using the top 20% and 30% thresholds, respectively, show consistent findings. Fig. 6a reports results from a logit

model in which the dependent variable is a dummy indicating whether a block group is identified as a mobility desert. Fig. 6b reports OLS estimates using the continuous mobility index as the outcome, where higher values indicate greater mobility deprivation. Both models include the same set of socioeconomic variables used in the earlier binary and quartile comparisons and yield broadly consistent results.

Across specifications, the shares of male residents and children, as well as median household income, are negatively associated with mobility deprivation, indicating that block groups with fewer male residents, fewer children, and lower incomes tend to experience more severe mobility constraints. In contrast, total population, the shares of seniors and Black residents, the unemployment rate, and the share of residents with a bachelor's degree are positively associated with the mobility index, suggesting that mobility deprivation is more pronounced in block groups characterized by larger populations, older age profiles,

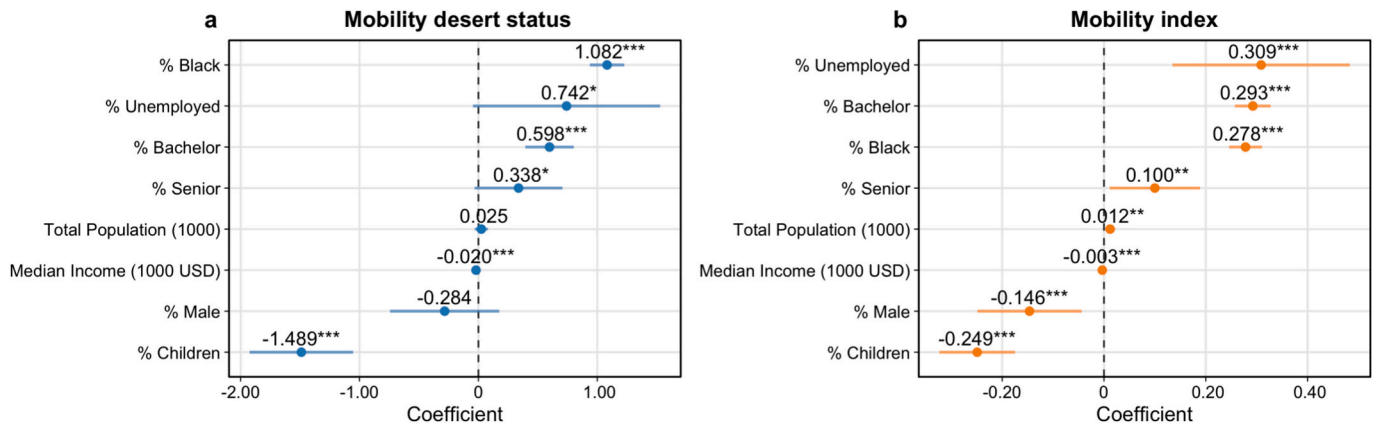


Fig. 6. Regression results.

higher unemployment, and greater racial and educational concentration.

Taken together, the descriptive comparisons and regression estimates provide consistent evidence that mobility deprivation is associated with socioeconomic vulnerability. The regression models further show that these patterns remain evident in a multivariate framework with metropolitan-area fixed effects. It should be emphasized, however, that because the analysis is based on cross-sectional data, these findings should be interpreted as associational rather than causal.

4.3. Emerging mobility services

To assess whether bike-sharing services can help alleviate mobility desert conditions, Fig. 7 compares bike-sharing accessibility between mobility desert and non-mobility desert block groups. Supplementary Figs. S5 and S6 using the top 20% and 30% thresholds, respectively, show consistent findings. As shown in Fig. 7a, mobility deserts exhibit higher bike-sharing station density than non-mobility desert areas (24.1 vs. 21.6 bike-sharing stations per block group, $P = 0.049$), suggesting greater availability of emerging transportation options where traditional

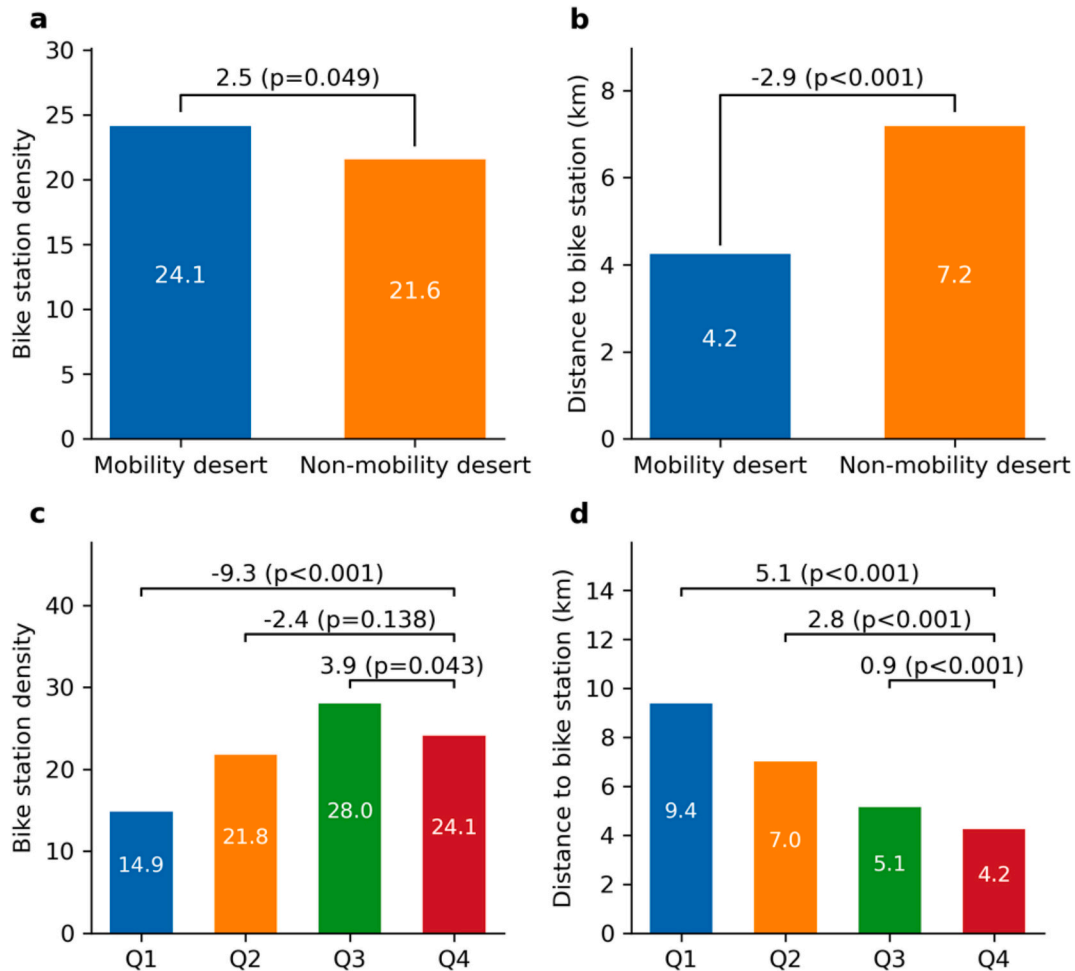


Fig. 7. Disparities in access to bike-sharing stations between mobility deserts and non-mobility deserts.

mobility is more limited. Consistent with this pattern, Fig. 7b shows that mobility desert block groups are located significantly closer to the nearest bike-sharing station than non-mobility desert block groups (4.2 km vs. 7.2 km, $P < 0.001$), indicating more spatially concentrated bike-sharing infrastructure in mobility-deprived areas.

Fig. 7c further disaggregates bike-sharing station density by quartiles of the mobility index (Q1–Q4). Station density generally increases with mobility deprivation, with Q3 and Q4 block groups exhibiting higher densities than Q1 and Q2, and Q3 showing the highest average density. A complementary pattern emerges in Fig. 7d, which compares distance to the nearest bike-sharing station across quartiles: block groups in Q1 (least mobility-deprived) are farthest from bike stations (9.4 km), whereas Q4 block groups (most mobility-deprived) are closest (4.2 km). Together, these results indicate a positive association between mobility deprivation and bike-sharing accessibility, suggesting a potential supplementary role for bike-sharing in selected mobility desert neighborhoods.

To further examine the relationship between bike-sharing infrastructure and mobility deprivation, Fig. 8 presents correlations between bike-sharing accessibility and the mobility index, as well as key mobility-related characteristics, including the share of carless households, distance to the nearest Metrorail station, and bus stop density. Fig. 8a shows a small but statistically significant positive correlation between the mobility index and bike-sharing station density ($r = 0.017$, $P = 0.011$), indicating that block groups with higher mobility deprivation tend to host slightly denser bike-sharing infrastructure. Consistent with this pattern, Fig. 8b reveals a moderate positive correlation between bike-sharing station density and the percentage of carless households ($r = 0.331$, $P < 0.001$), suggesting that bike stations are more prevalent in areas with greater reliance on non-automobile transportation. In contrast, Fig. 8c shows a negative correlation between bike-sharing station density and distance to the nearest Metrorail station ($r = -0.127$, $P < 0.001$), implying lower bike-sharing availability in areas farther from rapid transit. Fig. 8d further indicates a strong positive association between bike-sharing station density and bus stop density ($r = 0.402$, $P < 0.001$), reflecting co-location of alternative transportation modes.

Figs. 8e–h examine correlations involving the distance to the nearest bike-sharing station. Fig. 8e shows a negative correlation between this distance and the mobility index ($r = -0.159$, $P < 0.001$), indicating that more mobility-deprived areas tend to be located closer to bike stations.

Similarly, Fig. 8f reveals a strong negative correlation between the share of carless households and distance to the nearest bike-sharing station ($r = -0.404$, $P < 0.001$), suggesting that residents without private vehicles generally have better proximity to bike-sharing services. Fig. 8g shows a positive correlation between distance to the nearest Metrorail station and distance to the nearest bike-sharing station ($r = 0.488$, $P < 0.001$), indicating that remoteness from rail transit is associated with weaker bike-sharing access. Finally, Fig. 8h presents a moderate negative correlation between bus stop density and distance to the nearest bike-sharing station ($r = -0.299$, $P < 0.001$), implying that areas with denser bus networks tend to have closer access to bike-sharing infrastructure. These correlations further suggest that bike-sharing infrastructure is not evenly distributed across neighborhoods with the weakest traditional transit access. Instead, it appears to function primarily as a complementary service clustered around existing transit networks, indicating that its capacity to alleviate mobility deprivation is spatially uneven and limited.

5. Discussion

5.1. Socioeconomic inequalities in urban mobility

Our results indicate that mobility deserts are closely intertwined with broader patterns of socioeconomic inequality across U.S. metropolitan areas. Census block groups with higher shares of Black residents, lower household incomes, and higher unemployment rates are significantly more likely to experience severe mobility deprivation. These patterns suggest that mobility deserts are not randomly distributed across urban space; instead, they are embedded within and likely reinforced by existing socioeconomic structures.

This finding aligns with prior research showing that disadvantaged populations often face disproportionate barriers to transportation access, leading to forms of transport-related social exclusion (Lucas, 2012). Similarly, scholarship on transportation equity emphasizes that unequal distributions of mobility resources can exacerbate and reproduce socioeconomic inequalities within cities (Pereira et al., 2017). Long-standing processes such as residential segregation, uneven infrastructure investment, and spatial mismatches between housing and employment have further contributed to persistent accessibility disparities in many urban areas (Wang and Zhu, 2026).

From a transport justice perspective, mobility deserts therefore

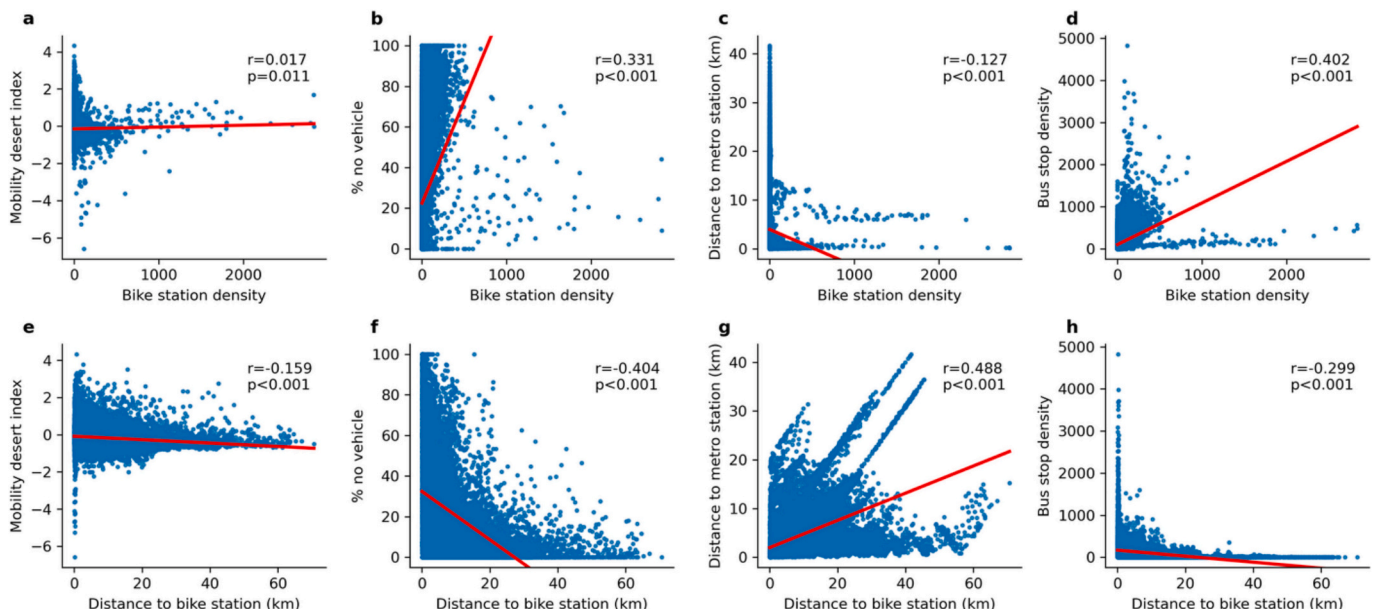


Fig. 8. Correlation between bike-sharing stations and mobility index and its components.

represent not merely deficiencies in transportation provision, but manifestations of deeper socio-spatial inequalities that constrain access to employment, education, healthcare, and other essential urban opportunities. As [Martens \(2016\)](#) argues, transportation systems should be evaluated based on how equitably they distribute accessibility across social groups. Our findings support this view by demonstrating that mobility deprivation systematically concentrates in communities already facing economic and social vulnerability, underscoring the need for equity-oriented mobility and infrastructure policies.

5.2. Bike sharing in addressing urban mobility gaps

The finding that bike sharing may provide supplementary mobility options in selected mobility-deprived areas has important implications for urban transportation policy. Compared with traditional transit investments, which typically require substantial capital expenditures and long planning horizons, bike-sharing systems offer a relatively low-cost and flexible means of expanding mobility options in neighborhoods where both public transit access and private vehicle ownership are limited. Prior research shows that well-integrated bike-sharing systems can reduce average travel times and improve the overall efficiency of urban transportation networks, particularly by complementing existing transit services ([Yang et al., 2018](#)). Evidence from U.S. cities further suggests that bike sharing can enhance mobility resilience and reduce dependence on fixed-route systems in underserved areas ([Jin and Sui, 2024](#)). From a policy perspective, targeted station placement, fare subsidies for low-income users, and integration with public transit payment systems are critical to ensuring that micromobility services expand access equitably rather than exacerbating existing spatial inequalities ([Beale et al., 2023](#)).

At the same time, our analysis highlights important limitations in the extent to which bike-sharing systems can compensate for deficiencies in public transit infrastructure. Areas located farther from Metrorail stations also tend to be farther from bike-sharing stations, and neighborhoods with lower bus stop densities generally exhibit lower bike-sharing station densities. This spatial pattern suggests that bike-sharing infrastructure is more likely to co-locate with existing transit investments than to extend mobility into transit-deprived areas. Consistent with prior research, bike sharing thus appears to function primarily as a complement to public transit rather than a substitute. For example, [Martin and Shaheen \(2014\)](#) show that many bike-sharing trips support first- and last-mile connections rather than replacing transit travel altogether. Taken together, these findings indicate that while micromobility may help ease mobility constraints in selected contexts, it is unlikely to address the structural causes of mobility deserts on its own. Reducing mobility deprivation therefore requires a broader, coordinated strategy that combines sustained investments in public transit infrastructure with the targeted deployment of micromobility services in underserved neighborhoods.

6. Conclusions

This study develops a mobility index that captures joint deficits in public transit access and private vehicle availability, enabling the identification of “mobility deserts” in major U.S. metropolitan areas. The results reveal pronounced socioeconomic disparities. Census block groups classified as mobility deserts are typically economically and socially vulnerable communities, characterized by significantly lower incomes, higher unemployment, and lower educational attainment compared to other areas. These findings underscore the structural nature of urban mobility inequality and highlight the value of the mobility index as a tool for diagnosing transportation deprivation.

Emerging mobility services such as bike sharing may provide supplementary mobility options in selected mobility-deprived neighborhoods. However, our findings indicate that these services mainly complement existing public transit networks and do not address the

structural roots of mobility inequality. Therefore, mitigating mobility deserts will require a holistic, equity-oriented strategy. Combining sustained investments in public transit infrastructure with the targeted expansion of new mobility services in underserved neighborhoods can effectively improve accessibility and reduce transportation inequities.

Despite its contributions, this study has several limitations that suggest avenues for future research. First, the mobility index and our data sources are subject to constraints, where we rely on cross-sectional census and infrastructure data that do not capture transit service quality (e.g. frequency or reliability) or dynamic travel behavior changes over time. Consequently, the findings may not reflect temporal shifts or causal relationships. Longitudinal studies or real-time mobility data could further validate and refine the results. Second, we acknowledge that commuting mode shares from the Census used to construct the mobility index do not fully capture all forms of everyday mobility, including non-work trips related to shopping, healthcare, education, caregiving, or recreation. As a result, the mobility index in this study shall be interpreted as a measure of structural mobility deprivation rather than a comprehensive representation of all travel behavior. Third, the scope is confined to nine large metropolitan areas with Metrorail systems, which may limit generalizability to smaller cities, rural areas, or regions without heavy rail transit. Future research should apply the mobility desert framework in diverse geographic contexts to test its broader applicability. Third, our evaluation of emerging mobility services focuses primarily on bike-sharing availability, whereas other modes like ride-hailing or e-scooters were not directly examined due to data limitations. Expanding analyses to include these and other evolving mobility options, as well as assessing their usage patterns in mobility-deprived areas, would provide a more comprehensive understanding of how new transport services can contribute to reducing mobility deserts.

CRedit authorship contribution statement

Hao Chen: Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Guimin Zhu:** Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Haoluan Wang:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Conceptualization. **Shenchao Han:** Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jtrangeo.2026.104804>.

Data availability

Data will be made available on request.

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